



Accelerated Insertion of Materials - Composites



Presented to the Engineering Foundation
by

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**Jointly accomplished by BOEING and the U.S Government under the
guidance of NAST**

This program was developed under the guidance of Dr. Steve Wax and
Dr. Leo Christodoulou of DARPA. It is under the technical direction of
Dr. Ray Meilunas of NAVAIR.





Overview

Accelerated Insertion of Materials (AIM)

AIM Objective:

Develop and validate new approaches for materials development that will accelerate the insertion of materials into production hardware

Phase 1 Basic Program -- 15 months (ends May 1992)

Proof of concept demonstration using existing material

Phase 1 Option Program -- 27 months

Complete development for existing material

"Blind" validation by independent team

Phase 2

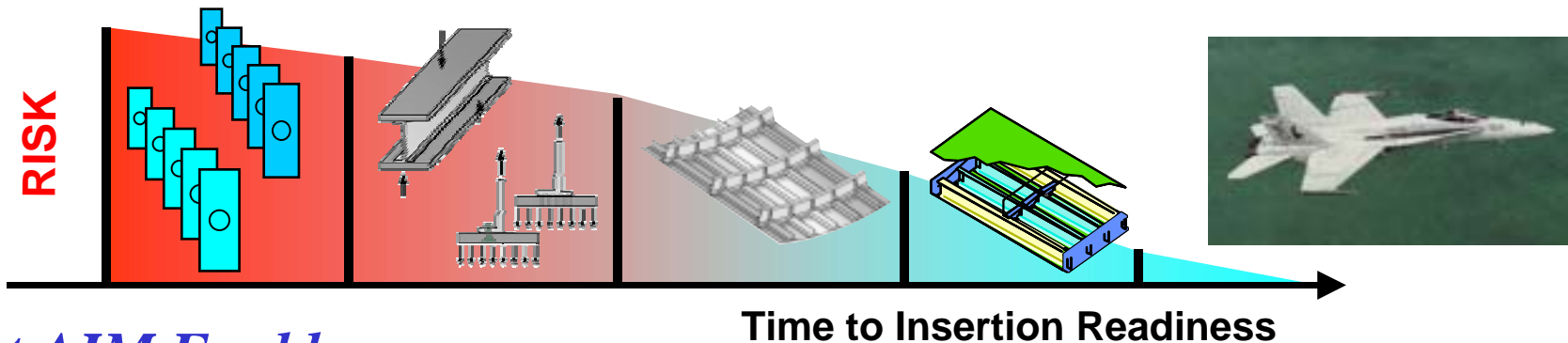
Make Phase 1 system generic



Accelerated Insertion of Materials



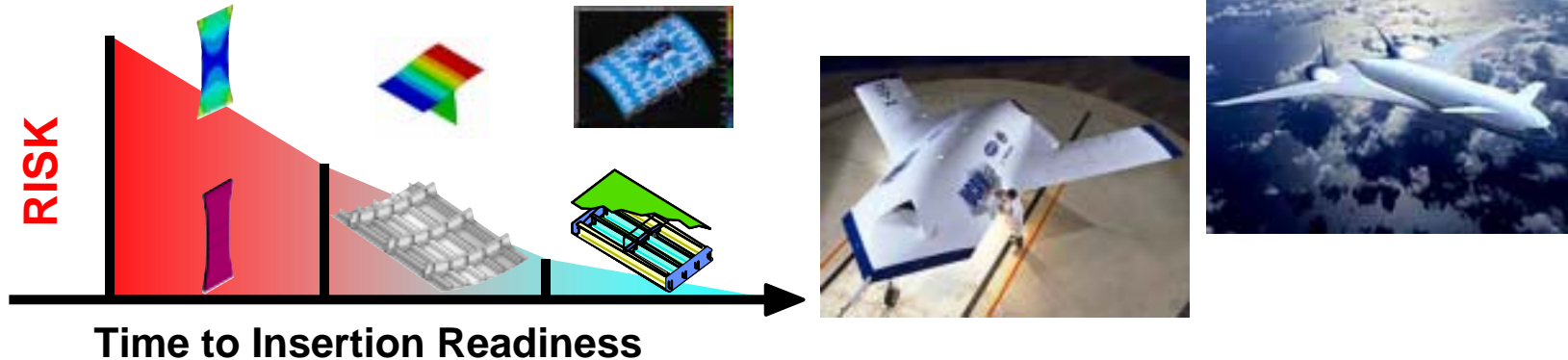
Traditional Building Block Approach Improves Confidence
by Extensive Testing Supported by Analysis:
Too Often Misses Material Insertion Windows



What AIM Enables

AIM Methodology Improves Confidence More Rapidly & Effectively by
Analysis Supported By Test / Demonstration -

Focusing on the Designer Knowledge Base Needs





- Performance
- Cost
- **Confidence** in materials database (especially variance)
 - Measured properties
 - Predicted properties
 - Producibility

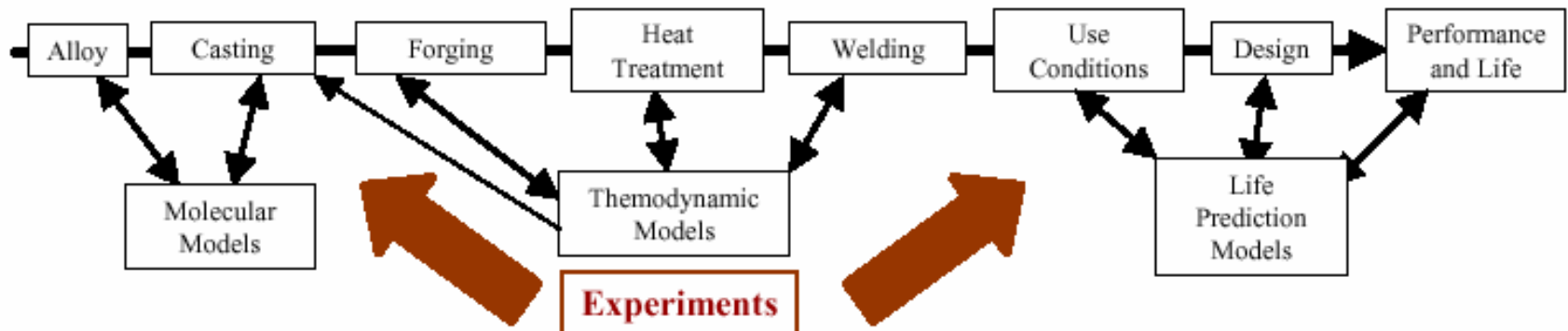
Confidence in the material is intimately tied to the reliability of knowledge of the state of the material throughout production and use.



Complex Interactions in Materials Processing



Defense Sciences Office



- **Independent Models Uncoupled to Developing Performance, Life (Designer Knowledge Base) Information**
 - Resulting Microstructures Not Useful for Input to Other Models
 - Precision/Accuracy Unknown, Not Useable in Other Models
 - Assumptions Internally Contained Not Transferable
 - Doesn't Consider Non-Linear, Non-Continuous Behavior Of Dependent Process Steps
- **Experiments Have Same Limitations!**

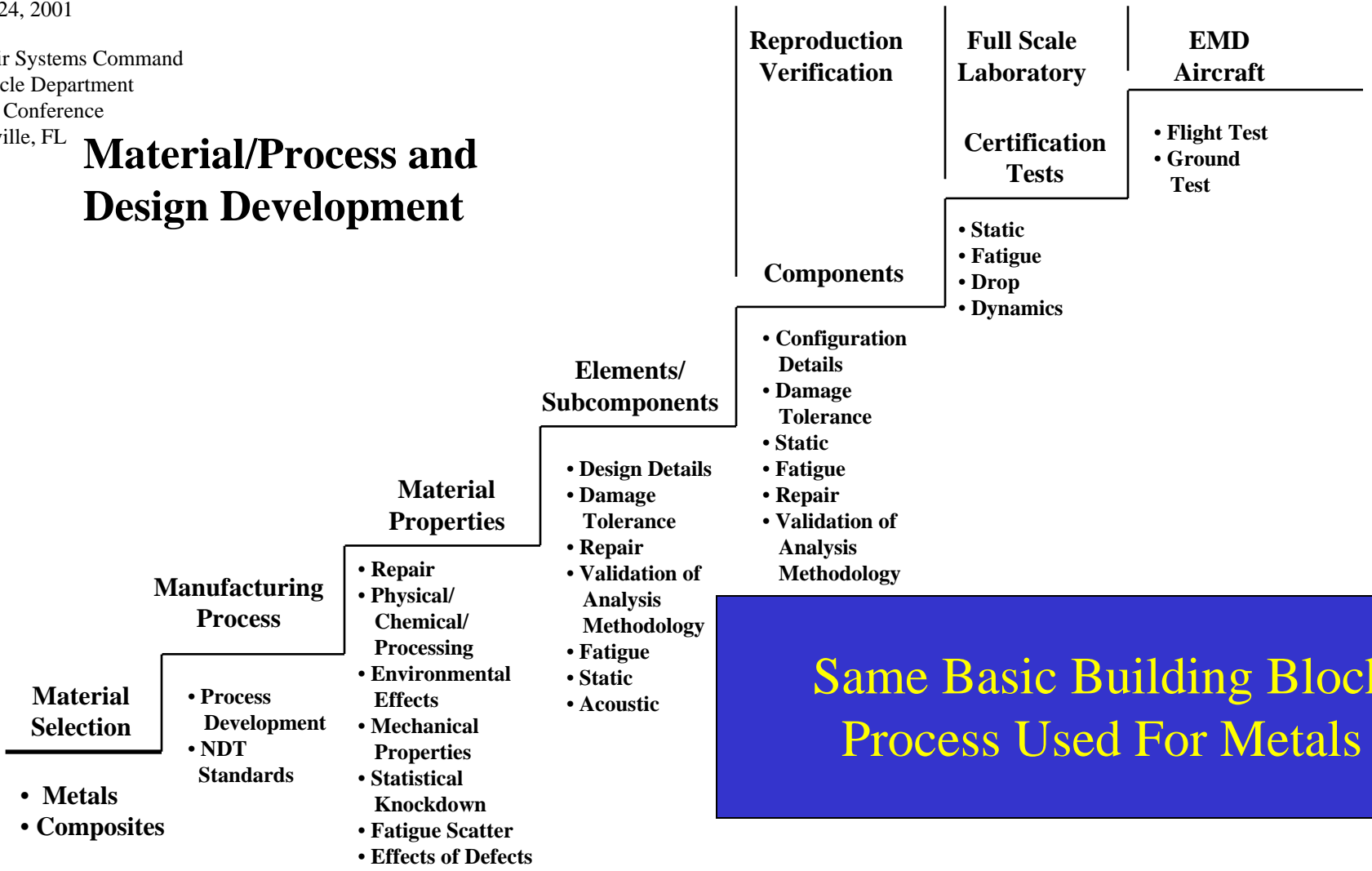


Kathryn L. Nesmith,
Roland Cochran and Denise Wong

May 21-24, 2001

Naval Air Systems Command
Air Vehicle Department
National Conference
Jacksonville, FL

Material/Process and Design Development



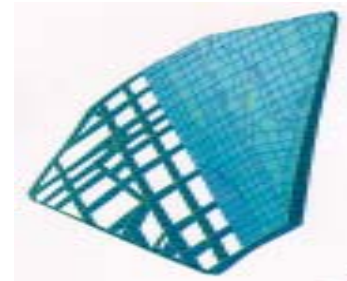
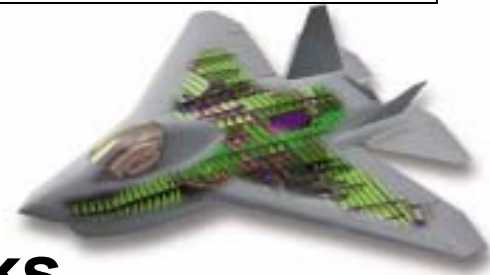
Same Basic Building Block Process Used For Metals





Focus Testing and Reduce Reliance on Empirical Point Design

Validate the Design and Analysis



Concept Selection and Development

Building Blocks

Supporting Technologies
Analysis

Full-Scale Tests (1 to 3)

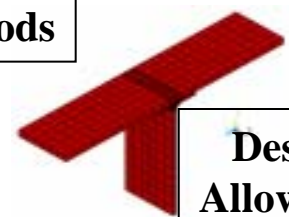
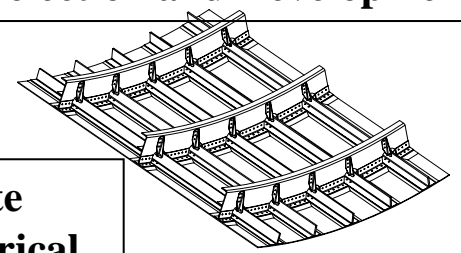
Component Tests (3 to 10)

Subcomponent Tests (~250)

Element Tests (~2000)

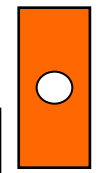
Coupon Tests (~8000)

Calibrate
Semi-Empirical
Analysis Methods



Design Allowables

Characterize the Material





DESIGN TEAM'S NEEDS

Requirements are Multi-Disciplined

Structural

- Strength and Stiffness
- Weight
- Service Environment
 - Temperature
 - Moisture
 - Acoustic
 - Chemical
- Fatigue and Corrosion Resistant
- Loads & Allowables
- Certification

Manufacturing

- Recurring Cost, Cycle Time, and Quality
- Use Common Mfg. Equipment and Tooling
- Process Control
- Inspectable
- Machinable
- Automatable
- Impact on Assembly

Supportability

- O&S Cost and Readiness
- Damage Tolerance
- Inspectable on Aircraft
- Repairable
- Maintainable
 - Accessibility
 - Depaint/Repaint
 - Reseal
 - Corrosion Removal
- Logistical Impact

Material & Processes

- Development Cost
- Feasible Processing Temperature and Pressure
- Process Limitations
- Safety/Environmental Impact
- Useful Product Forms
- Raw Material Cost
- Availability
- Consistency

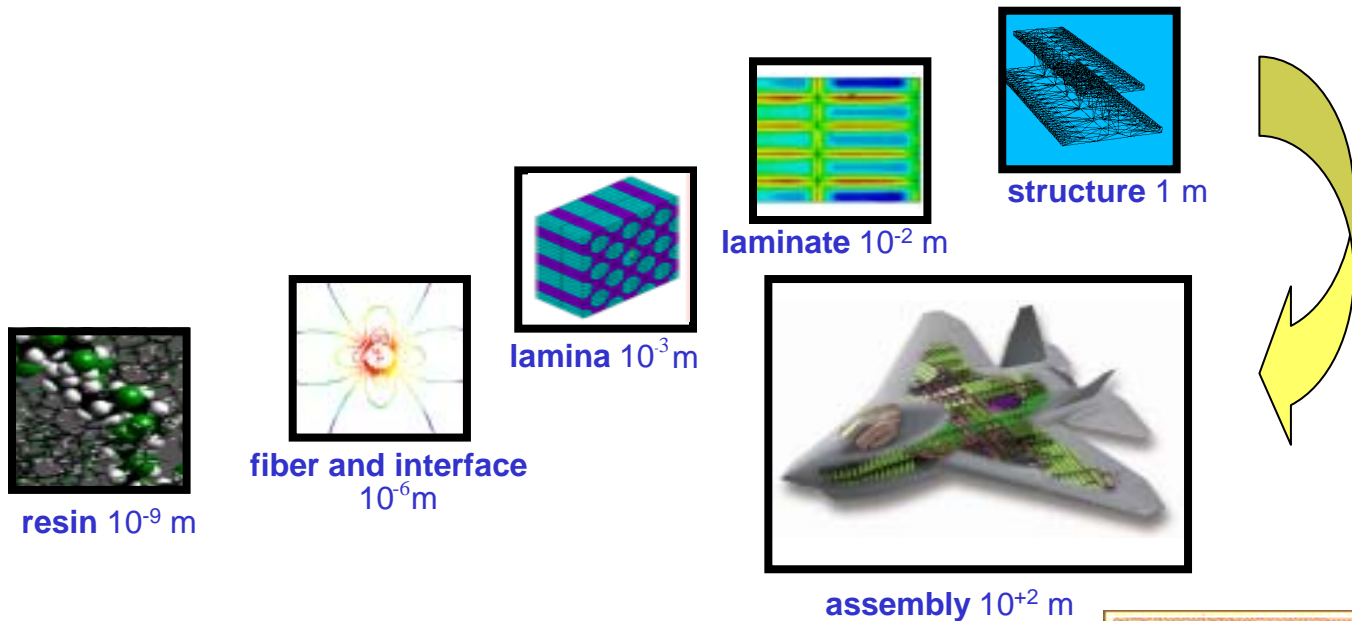
Miscellaneous

- Observables
- EMI/Lightning Strike
- Supplier Base
- Applications History
- Certification Status
 - USN
 - USAF
 - ARMY
 - FAA

Risk in Each Area is Dependent Upon Application's Criticality and Material's Likelihood of Failure

- Home
- Application
- Certification
- Assembly
- Design
- Supportability
- Cost
- Schedule
- Strength
- Fabrication
- Quality
- Mat'l & Proc
- Legal/Rights
- Output

Accelerated Insertion of Materials



Chemistry to Component in the
Shortest Time at Acceptable Risk

- Methodology
- Process
- New Features



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Application

Space Vehicle

Missile

Launch Vehicle

Commercial Transport

Military Transport

Tactical Aircraft

Bomber

Rotary Wing

Tanker

Uninhabited Vehicle

Ground Vehicle

Structural Criticality

Non-Structural

Secondary Structure

Primary Structure

Flight Critical Structure

Usage Environment

Flight Loads Usage

Design Service Life

Temperature

Chemical Environments



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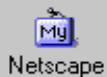
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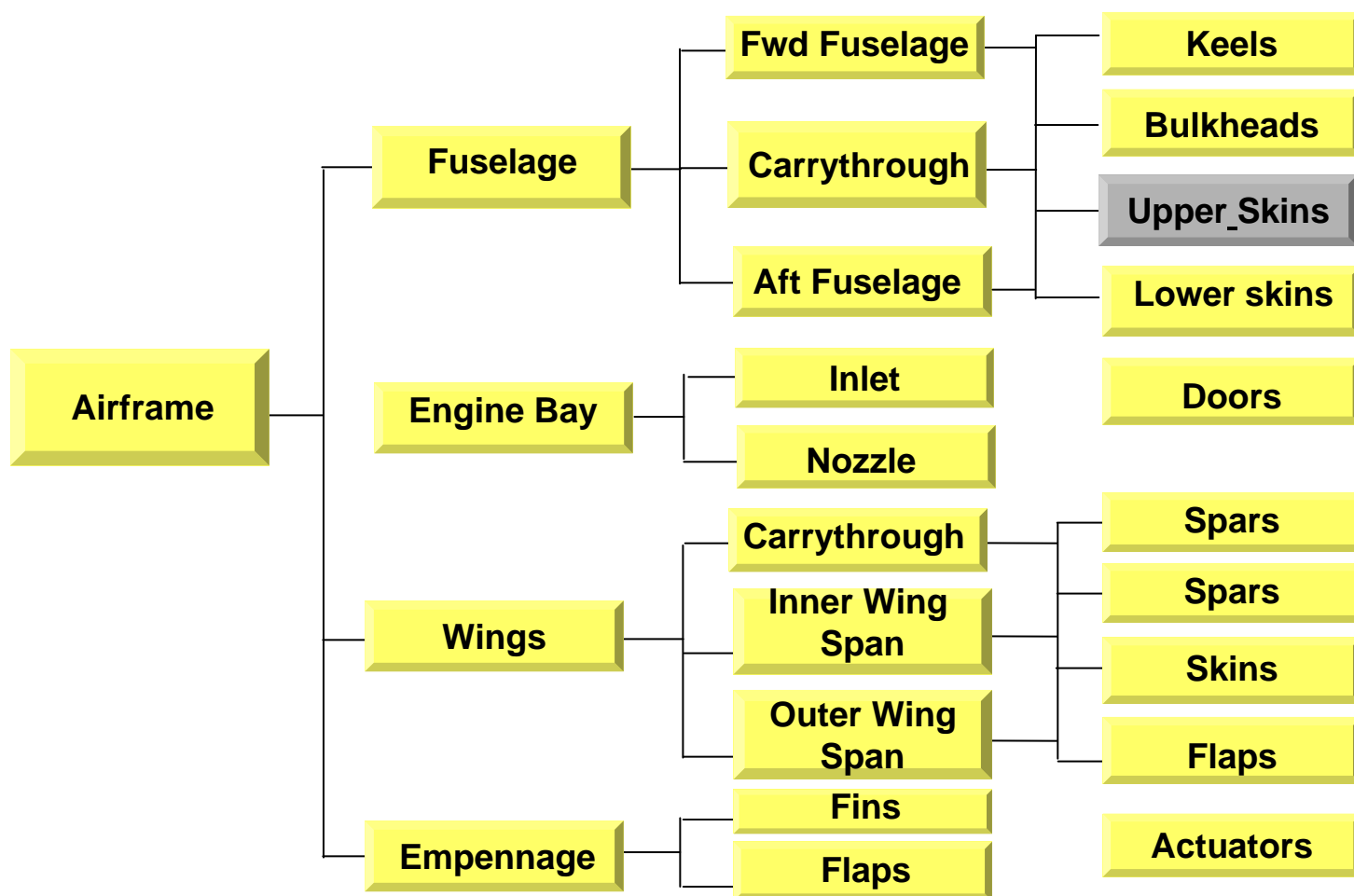
Welcome to AIM-C Program

File Edit View Go Communicator Help Yahoo!



Bookmarks Netsite: <http://darpa.org/aim.navy.mil>

- Home
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AIM-C



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Back



Forward



Reload



Home



Search



Netscape



Print



Security



Stop



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http: darpa.org/aim.navy.mil

Home

Application

Certification

Assembly

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Output

Part Complexity

Flat

Single Curvature: Large Radii

Single Curvature: Small Radii

Double Curvature : Large Radii

Double Curvature : Small Radii

Multi-Plane

Stiffened

Sandwich

Assembly Concept

Mechanically Fastened

Co-Cured

Bonded

Welded



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AIM-C



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Output

TRL	1	2	3	4	5	6	7	8	9	10
Application Maturity	Concept Exploration	Concept Definition	Proof of Concept	Preliminary Design	Design Maturation	Component Testing	Ground Test	Flight Test	Production	Recycle or Dispose
Application Risk	Very High	High	High - Med	Med - High	Medium	Med - Low	Low	Low - Very Low	Very Low	Negligible - Recycle or Disposal
Certification		Certification Plan Documented	Certification Plan Approved	Preliminary Design Allowables	Design Allowables / Subcomponents	Full Scale Component Testing	Full Scale Airframe Tests	Flight Test	Production Approval	Disposal Plan Approval
Assembly	Assembly Concept	Assembly Plan Definition	Assembly Definition	Assembly Details Tested	Subcomponents Assembled	Components Assembled	Airframe Assembled	Flight Vehicles Assembled	Production	Disassembly for Disposal
Design	Concept Exploration	Concept Definition	Design Closure	Preliminary Design	Design Maturation	Ground Test Plan	Flight Test Plan	Production Plan	Production Support	Disposal Support
Supportability		Repair Processes Identified	Repair Processes Documented	Fabrication Process Repairs Identified	Fabrication Repair Process Trials Subcomponent Repairs	Repair of Component Test Articles	Production Repairs Identified	Flight Qualified Repairs Documented	Repair / Replace Decisions	Support for Recycle or Disposal Decisions
Cost/Benefit Maturity	Cost Benefits Projected	ROM Cost Benefit Analysis	Cost / Benefit Analyses Reflect Lessons Learned	Cost / Benefit Analyses Reflect Sizing Lessons Learned	Cost / Benefit Analyses Reflect Component Assembly Lessons Learned	Cost / Benefit Analyses Reflect Vehicle Assembly Lessons Learned	Cost / Benefit Analyses Reflect Low Rate Production Lessons Learned	Production Support	Cost / Benefit Analyses Reflect Production Lessons Learned	Cost / Benefit Analyses Reflect Disposal Lessons Learned
Structures Maturity	Potential Benefits Predicted	Applications Revised by Lamina Data	Applications Revised by Laminate Data	Testing of Critical Details / Elements	Sub-Component Tests of Applications	Component Tests of Applications	Full Scale Aircraft Level Ground Tests	'Flight Qualified' via Test and Analysis	Flight Tracking / Production Support / Fleet Support	Retirement for Cause
Fabrication Maturity	Target Applications Identified	Target Application Processes Tested	Target Application Full Scale Trials / Assembly Methods Defined	Sized Sub-components Fabricated / Assembly Methods Tested	Sized Components Fabricated / Assembly Methods Refined	Fabrication & Assembly Methods Documented / Production Methods Defined	Low Rate Production for Flight Test Vehicles Begins	Low Rate Production	Production Support / Recycle or Disposal Methods Defined	Recycle or Dispose
Quality		Initial Inspection and Repair Processes Identified	Inspection Trials	Inspection and Repair Processes Identified	Inspection of Components	Inspection and Repair of Component Test Articles	Vehicle Inspection Plan Documented / Production Repairs Identified	Flight Qualified Repairs Documented	Repair / Replace Decisions	Support for Recycle or Disposal Decisions
Materials Maturity	Key Target Properties Defined from Chemistries	Key Target Properties Obtained in Test	Initial Property Reproducibility Tests	Design Properties Developed	Preliminary Allowables Available / Support Materials Identified	Design Allowables Available / Support Materials Tested	Ground Test Certification / Support Materials Qualified	Low Rate Production Support	Production Support / Recycle or Disposal Methods Defined	Support for Recycle or Disposal Decisions
Intellectual Rights										



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Strength

Tensile

σ_{11} (ksi)	σ_{22} (ksi)	σ_{33} (ksi)	σ_{23} (ksi)	σ_{13} (ksi)	σ_{12} (ksi)
370.6	7.32	7.32	11.6	11.6	11.6

Compressive

σ_{11} (ksi)	σ_{22} (ksi)	σ_{33} (ksi)	σ_{23} (ksi)	σ_{13} (ksi)	σ_{12} (ksi)
235.1	7.32	7.32	11.6	11.6	11.6

Stiffness

Young's Moduli (tensile)

Young's Moduli (compressive)

Poisson's Ratio

E_{11} (msi)	E_{22} (msi)	E_{33} (msi)	E_{11} (msi)	E_{22} (msi)	E_{33} (msi)	ν_{23}	ν_{31}	ν_{12}
24.367	1.347	1.347	22.946	1.347	1.347	0.325	0.325	0.325

Thermal

α_1 (in/in ⁰ F)	α_2 (in/in ⁰ F)	α_3 (in/in ⁰ F)
4.0×10^{-7}	2.0×10^{-5}	2.0×10^{-5}



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Recommended Tests for Your Requirements

Test Type	Number of Specimens				Emphasis	Specimen
	CTD	RTA	ETW	Total		
Lamina						
0° Tension	4	5	2	11	Fiber	Recommended
0° Compression	Fiber/Matrix	Recommended
45° Compression	Fiber/Matrix	Recommended
0° Interlaminar Shear	Fiber/Matrix	Recommended
.....		
Laminate						
Unnotched Tension	3	5	4	12	Stress Riser	Recommended
Open/Fill Hole Compression	Stress Riser	Recommended
Tension Bearing Interaction	Bearing Strength	Recommended
Compression Bearing Interaction	Bearing Strength	Recommended
.....		



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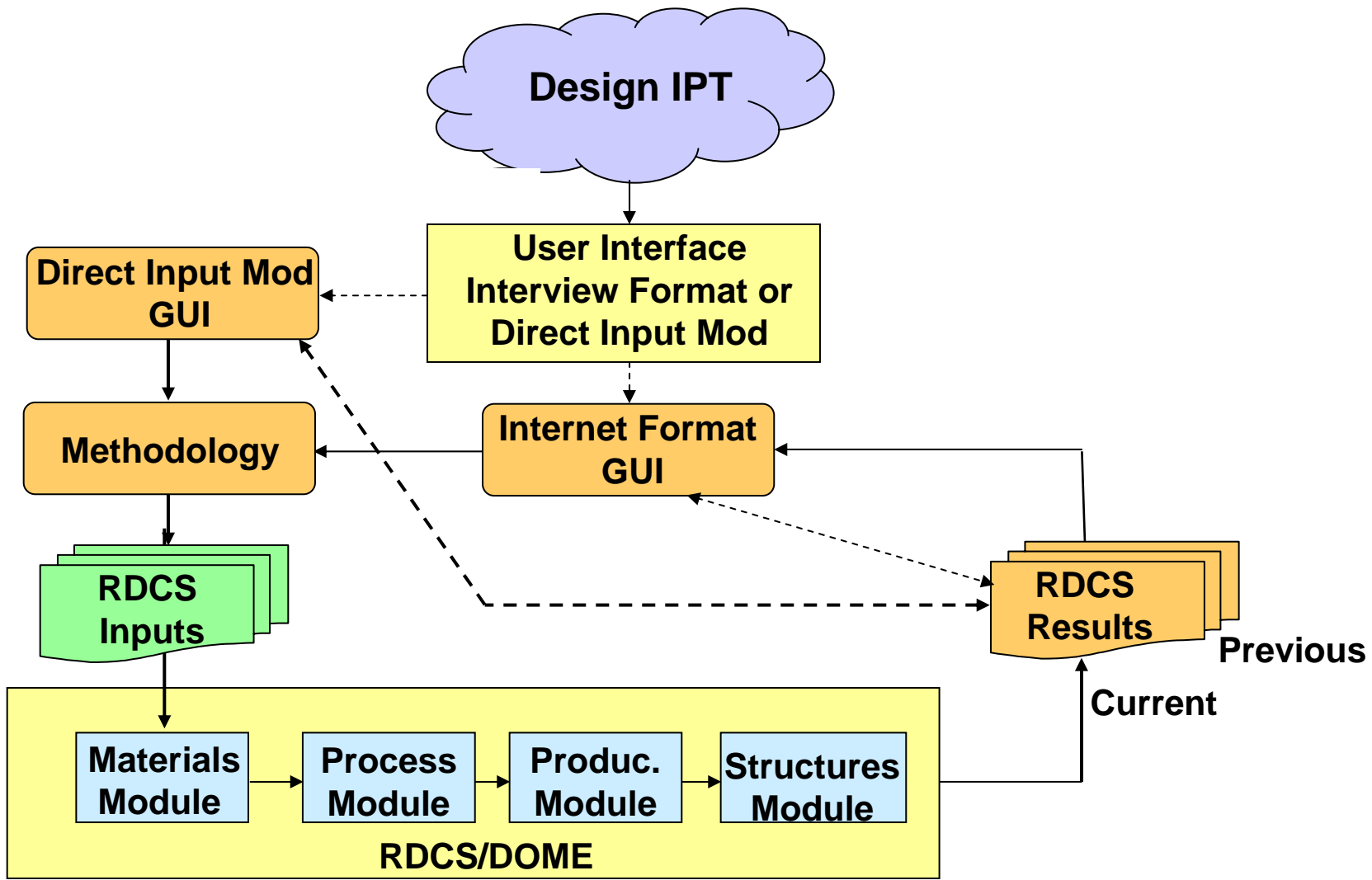
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Our Current Vision of the AIM Product





Methodology is the Foundation of the AIM-C Comprehensive Analysis Tool



RDCS/DOME Framework

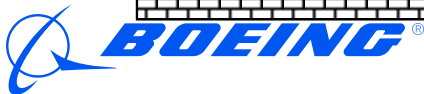
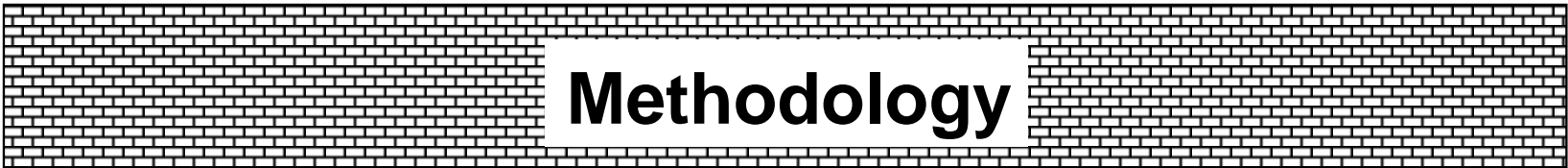
**Structure
Models**
(Science Based)

**Material & Process
Models**
(Science Based)

**Producibility
Models**
(Science Based)

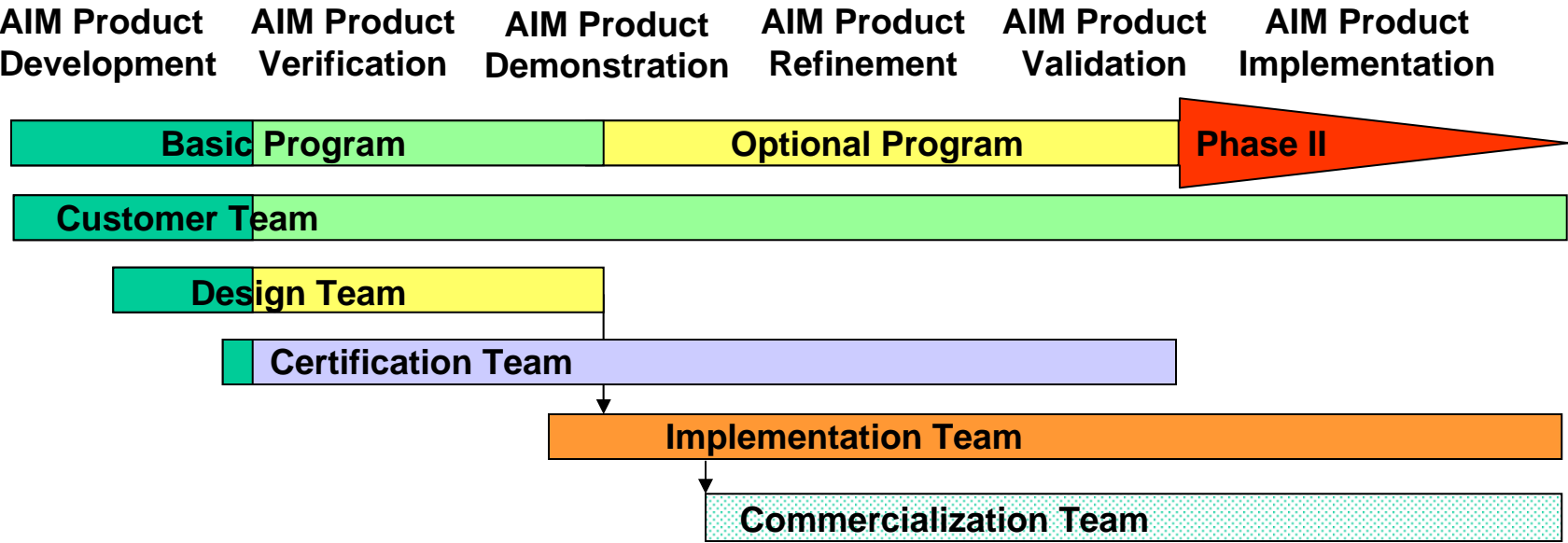
**Heuristic
Models**

Data Bases





Technology Transition Plan



Customer Team – To Insure that the Product Meets the Needs of the Funding Agents

Design Team – To Insure Acceptance Among User IPTs in Industry

Certification Team – To Insure Acceptance Among the Certification Agents for Structures

Implementation Team – To Insure Acceptance Among the User Community

Commercialization Team – To Insure Commercial Support of Users



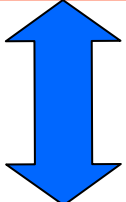


*The Certification Team Will Validate
Our Methodology and
Our Verification Approach*



Step 1

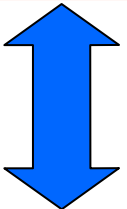
**Individual
Module
Validation**



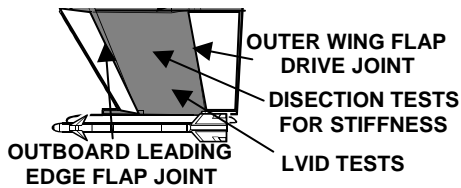
Existing Data

Step 2

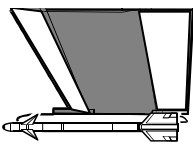
**Process
Validation**



**Existing
Subcomponent
Test Results**



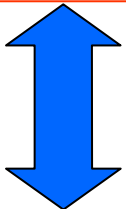
**Existing
Component
Test Results**



**& Tests of Wing Skin
Validate Projected
Means and Scatter**

Step 3

**System
Validation**



**Known
Design
Requirements**



**“Blind”
Subcomponent
Test Results**

**“Blind”
Component
Test Results**

Validates Technical Results, Time Reductions, Cost Reductions





Certification Team Feedback

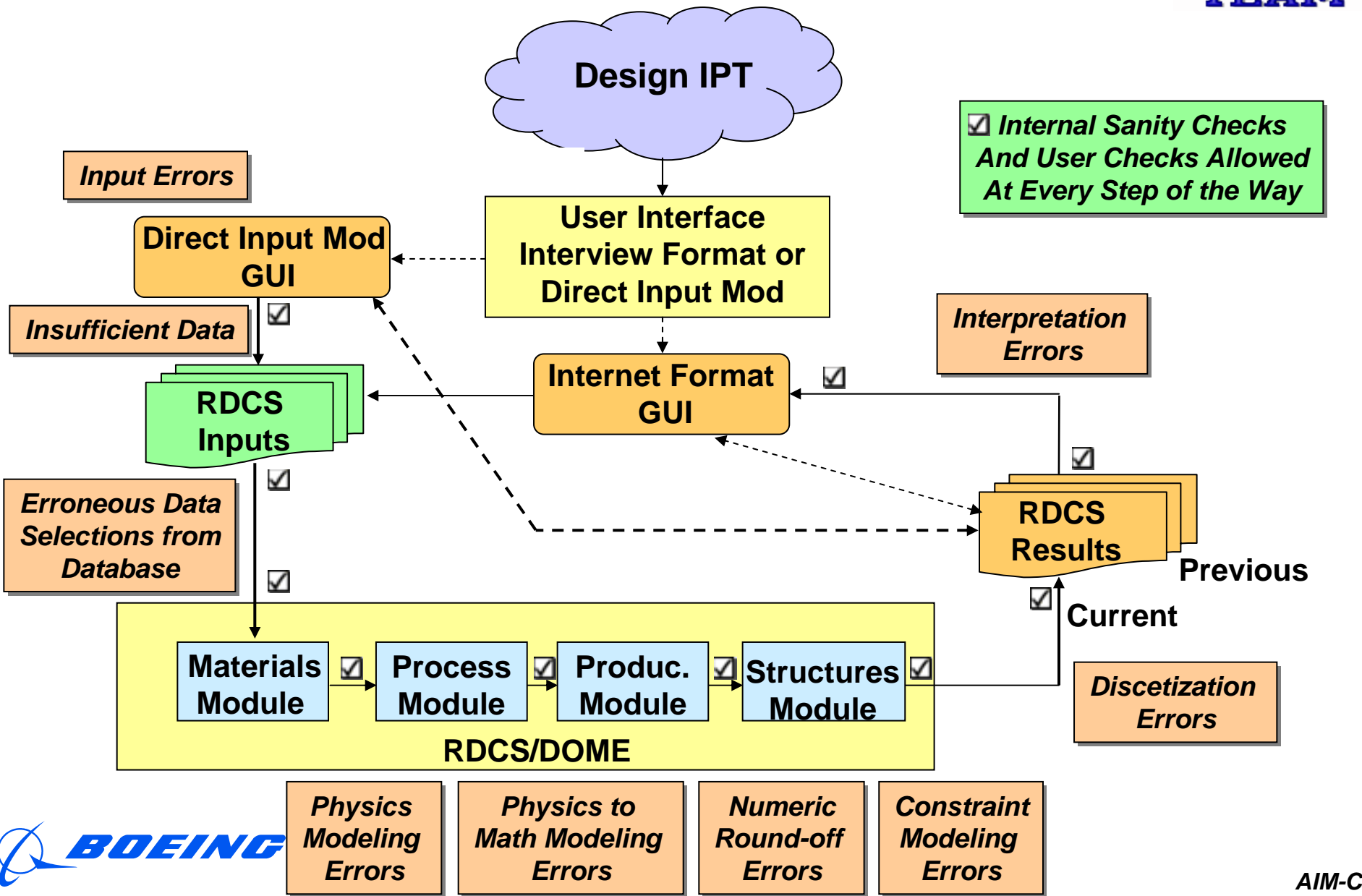
Roadblocks to Success



Limitations of the Process	Prediction Accuracy	Validation	Intellectual Property Rights	Technology Transition	Commercialization
This is a moving target depending on the modules being used and the data input. I think this goes beyond just knowing the 'errors'. We've seen before instances in which engineers who did not understand the limits of the software came out with answers tha	How does one insure that the company that actually builds the part can achieve the required properties? Additional testing?	There is going to have to be a lot of 'proof testing' (validation of AIM-C results) to convince the overall M&P/Structures community	Intellectual property rights to protect databases, test methodologies, and process specifications	Getting past 'Not Invented Here' or industry familiarization.	Developers leave and the certifiers of the next generation process are the next generation
Missing an important behavioral characteristic (ex., crystallinity in thermoplastics, free edge effects in laminates)	Unavailability of useful accurate models for specific technical areas will limit the scope of AIM.	Populating models with 'actual' values and distributions of variations	Protecting company proprietary information; magnitude of variations, costs, etc.	Getting past the "It will never work" crowd	Commercialization buy-in. What is the product?
Complexity of designing aircraft. There are thousands of issues to be considered. How is AIM going to capture them and deal with them in a logical fashion.	Will the producibility module really be able to identify fabrication show stoppers? As this point it is more a lessons learned from the past collection area.	Diversity and the extent of the validation activities (more contour, highly loaded, higher fatigue requirements)	Proprietary limitations: Commercial marketing may limit access to non-Boeing data sources.	Certification of materials and structures has different rules depending on who is doing it, the ultimate use of the structure, history of certifying organization... Not sure the 'one size fits all' approach will work.	Training to make it work: expert vs casual users
Input data validation: To be universally accepted, data from a large array of sources will be required (i.e., a world standard, ala, MIL-HDBK-5). Who sets this up?	Ability to address long term exposure and fatigue data in a manner different from today. May have to rely on testing for this.	Validation data: gathering sufficient data to certify the multitude of constituent software tools resident in AIM. For instance data to certify strain invariant (if that will be the failure theory used).		Broad adoption by the user community when faced with the "not invented here" syndrome.	Selection of the appropriate time to commercialize. Too early (before the tool is really ready) could be fatal.
Overselling the program to user community on what CAT can and cannot predict, i.e., showstoppers.	Failure of multi-axially loaded composites still difficult to predict.	Can you really provide compelling evidence that you've validated the tool? Criticism could be that since you knew the answers, you developed a system that can regurgitate the answers.		Perception that this is just another big program with no practical value.	Commercialization plan. At the end of AIM, what? Where are the \$ for maintenance, improvements, advertising, and sales, training
Limited funding limits the scope of the program to results in specific technologies. It eliminates those not fully developed (i.e., RTM, fiber placement) resulting in loss of interest by user community, i.e., will not be able to please everybody.		Providing enough confidence to the user community for computational analysis to replace experimental testing for specific applications.		Unfamiliarity of the certification community with computational approaches will result in fall back to building block approach to materials certification.	Where are the \$ to support adoption by other industries, sites? Software, hardware, training, new personnel, revision practices, codes, standards
How far will AIM assist in better understanding composite / metal structure interactions?		Partial validation. Demo leaves loose ends in fatigue, environmental testing, and structural details.		"Not invented here" roadblock. Aim will be perceived as a Boeing only, or a Boeing subcompany process.	How do you partition AIM so that portions can be used before having to use the whole thing?
Can you include a prediction of risk versus benefit for different levels of materials development maturity?					Can AIM be structures so that portions can be spun off and used prior to validation of the whole system?



Error Sources and Mitigation in The AIM-C Product





Example of an Output Screen for the AIM-C CAT



Home

Application

Certification

Assembly

Design

Supportability

Cost

Schedule

Strength

Fabrication

Quality

Materials

Legal/Rights

Output

Strength

Stiffness

Thermal

Tensile

Compression

Young's Modulus

Poisson's Ratio

E_{11} (msi)	E_{22} (msi)	E_{33} (msi)
24.367	1.347	1.347

α_1 (in/in ⁰ F)
4.0×10^{-7}

Design Process Visualizer: Simulation Methods

Display Entity: CDF

Plot Type: 2DCurvePlot

X-Axis Label: σ_{12} (ksi)

Y-Axis Label: Cumulative Probability Distrib

Close Print Help Page: 1/1 Refresh

σ_{12} (ksi)
11.6

σ_{12} (ksi)
11.6

Design Process Visualizer: Simulation Methods

Display Entity: CDF

Plot Type: 2DCurvePlot

X-Axis Label: ν_{23}

Y-Axis Label: Cumulative Probability Distrib

Close Print Help Page: 1/1 Refresh

E_{33} (msi)	ν_{23}	ν_{31}	ν_{12}
1.347	0.325	0.325	0.325

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DARPA

NAVAL AVIATION SYSTEMS TEAM

BOEING

AIM-C

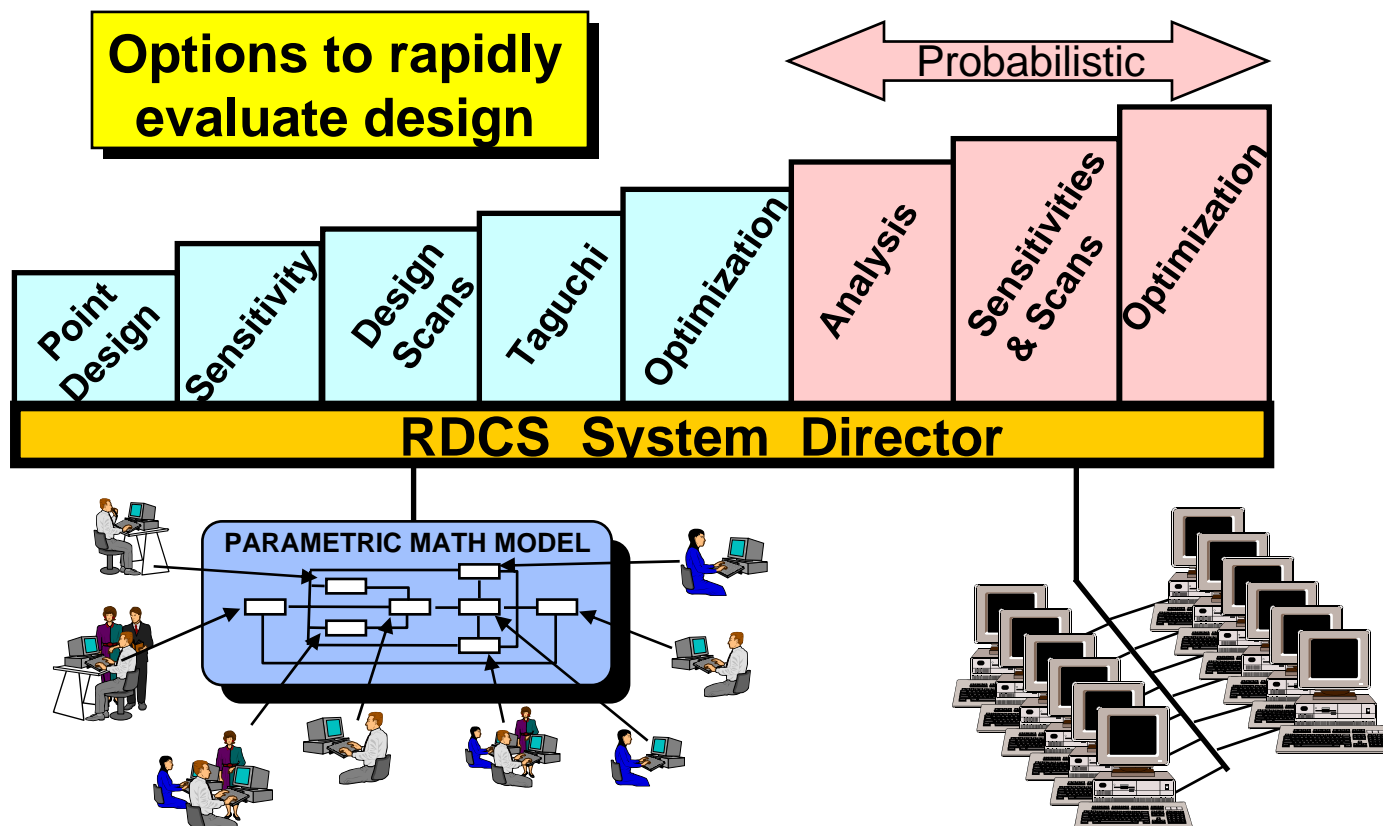
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Robust Design Computational System

(Commercially available from MSC Software)



Capture analysis & design process

Rapid parallel computing



Definition of Global Variables

Probabilistic Description

- Numerous Probabilistic Distribution Models Such As Normal, LogNormal, Weibull etc. are available for Characterizing The Variations

Probabilistic Description

Variable Name: hours_flowm (continuous)

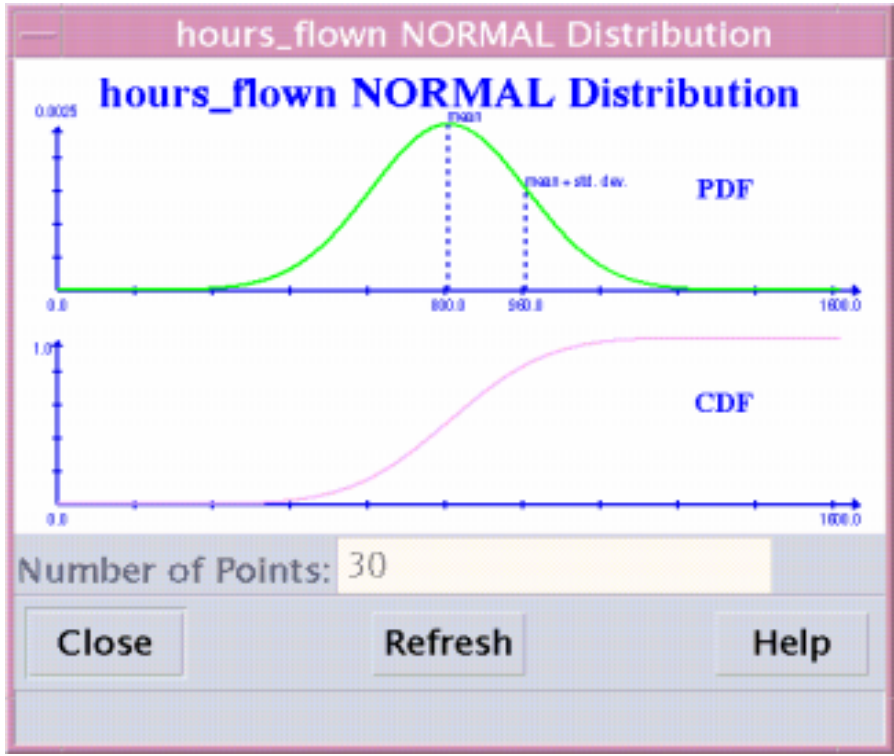
Source ID:

Description:

NORMAL

m_mean 800.0

m_stddev 160.0

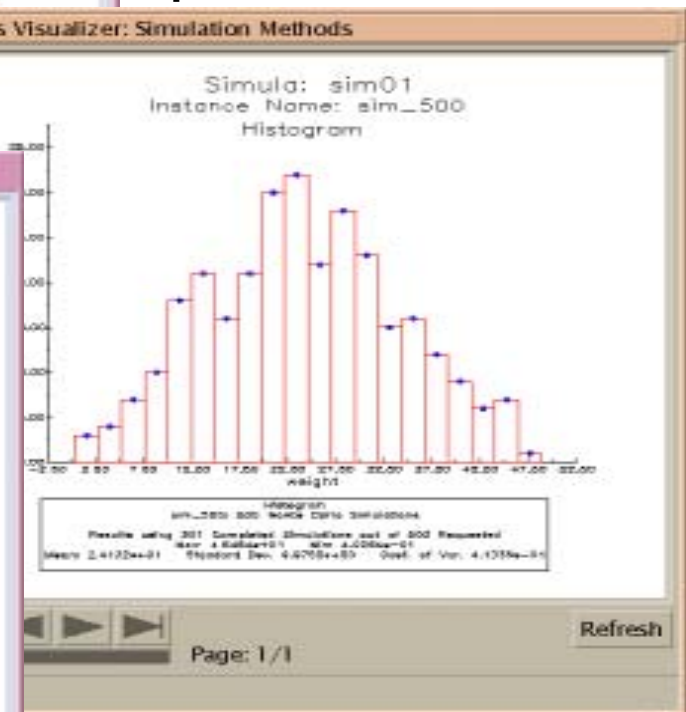
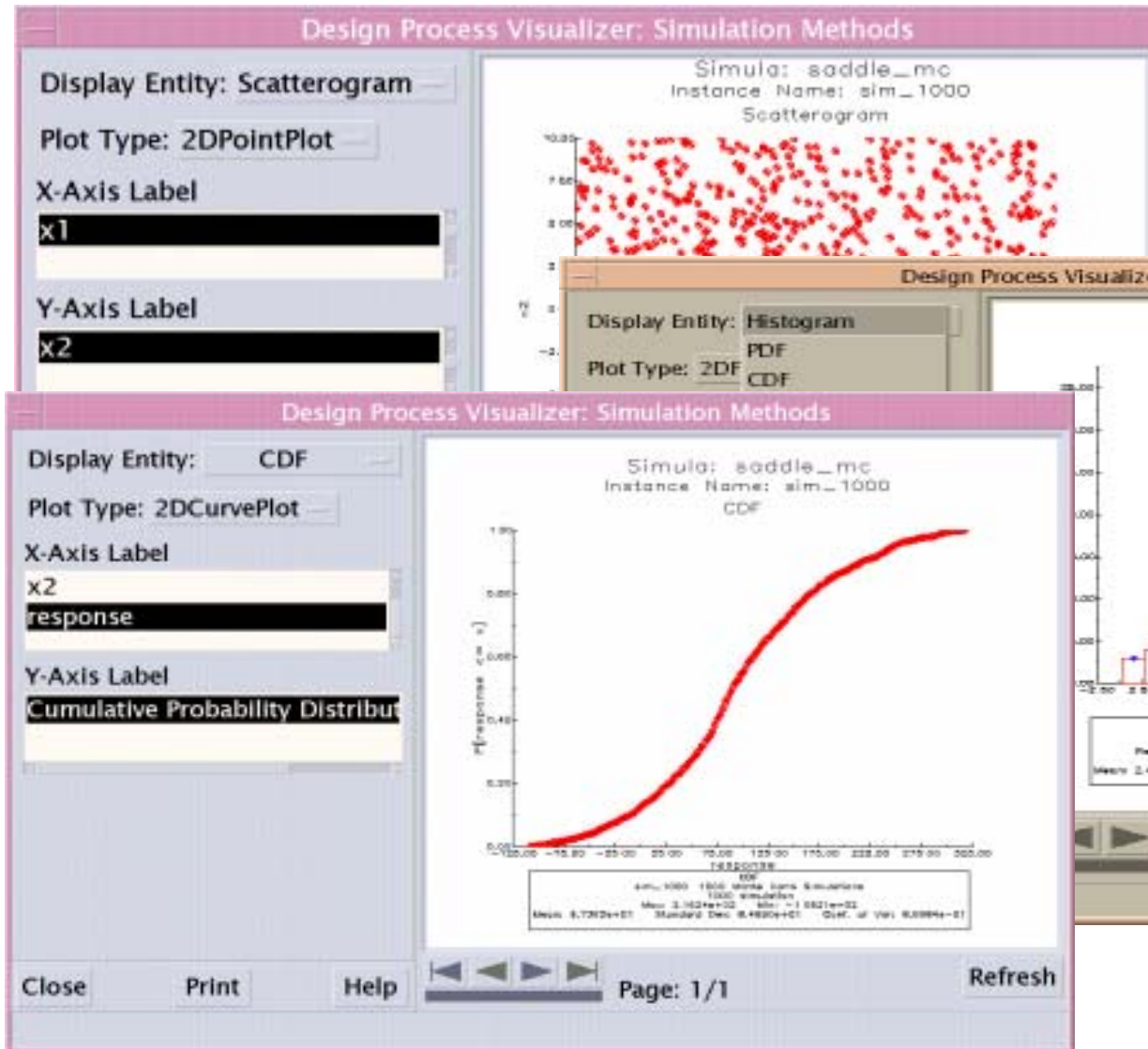




Uncertainty Analysis Results in Phase - 1

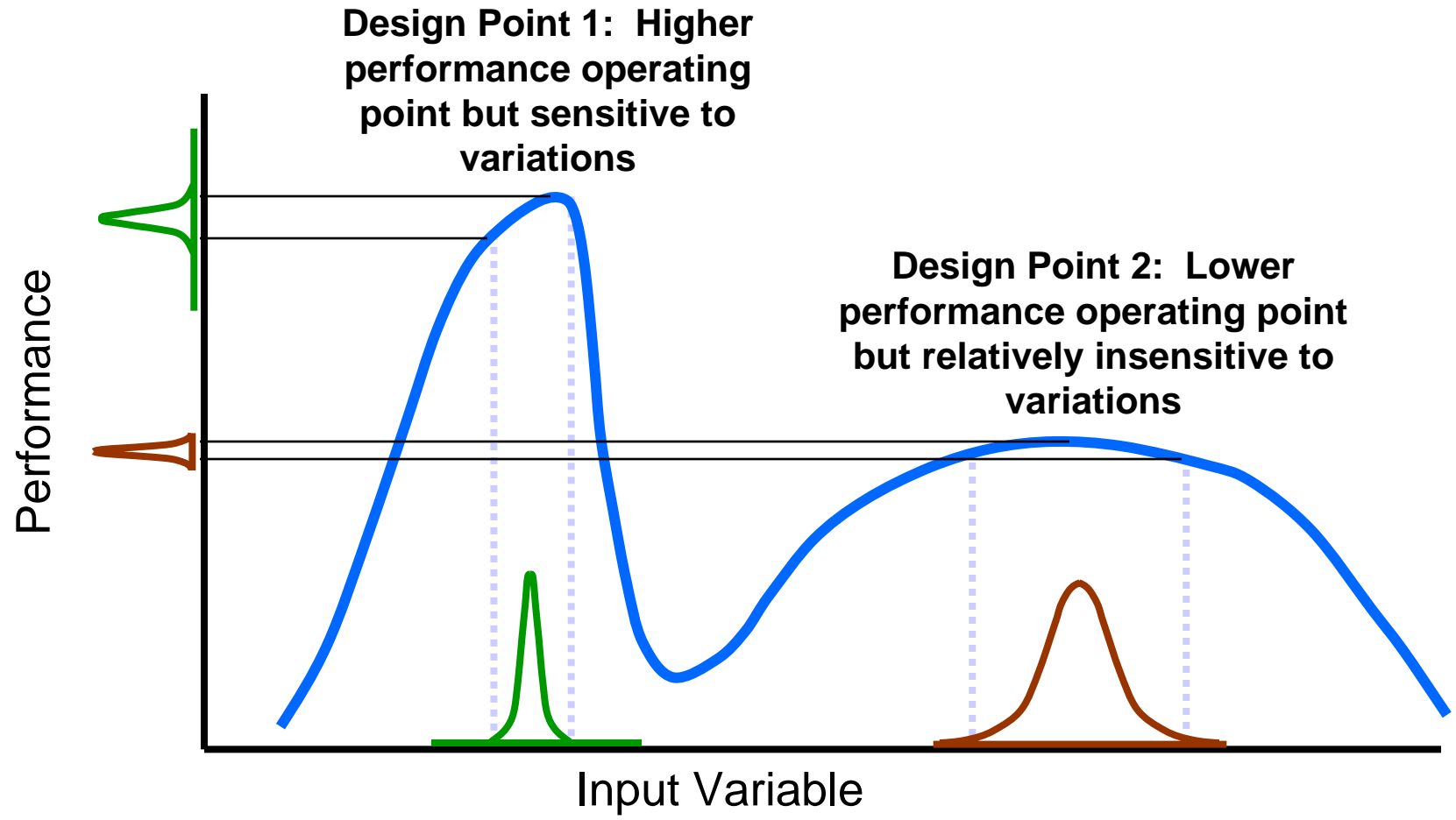


- Provides the effect of variability and/or uncertainties on design performance





Robust Design Illustrated Using Single Variable

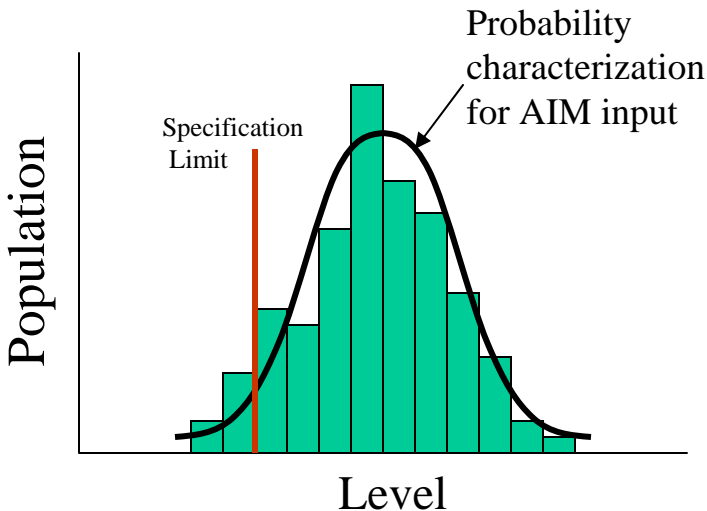
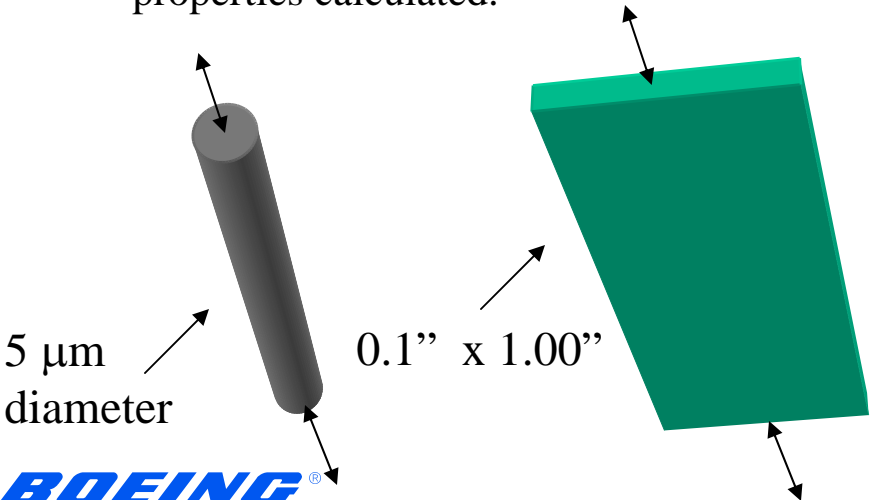




- Input Material Properties

- Test methods – accuracy, repeatability
- Distribution – data correlation, population

Example:
Fiber properties
single fiber tests not practical
Laminate tests performed, fiber
properties calculated.



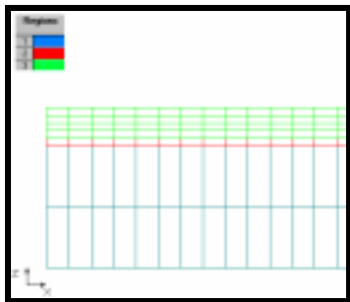
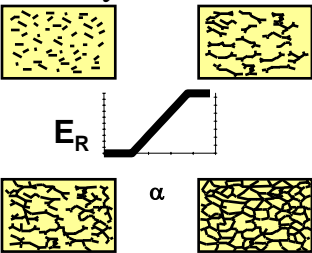
Example:
Actual data may not be ideal distribution
shape, Distribution of material actually
used may be truncated by specification
acceptance criteria



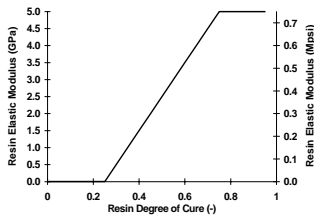
•Modeling

- Accuracy of physics
- Use of models outside of known limits
- Code Bug

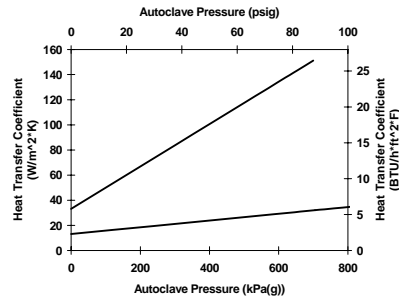
Example: The tool surface finish is not uniform for a tool or between tools.



Example: Physics of cure-hardening linear elastic versus fully viscoelastic



Example: Autoclave heat transfer equation is used outside of known limits

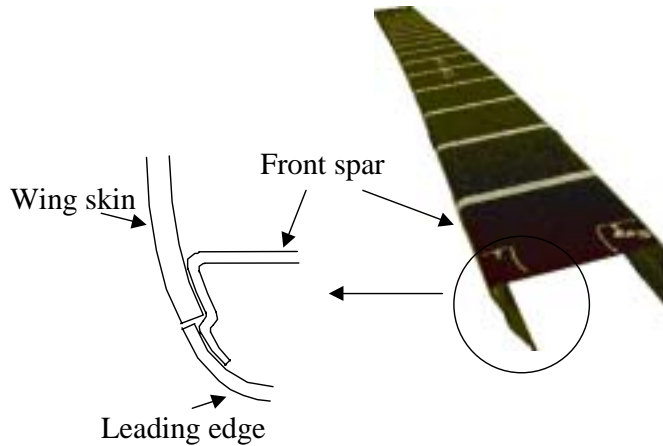




AIM-C CAT Benefits: COMPRO Integration with Robust Design Computational System (RDCS)



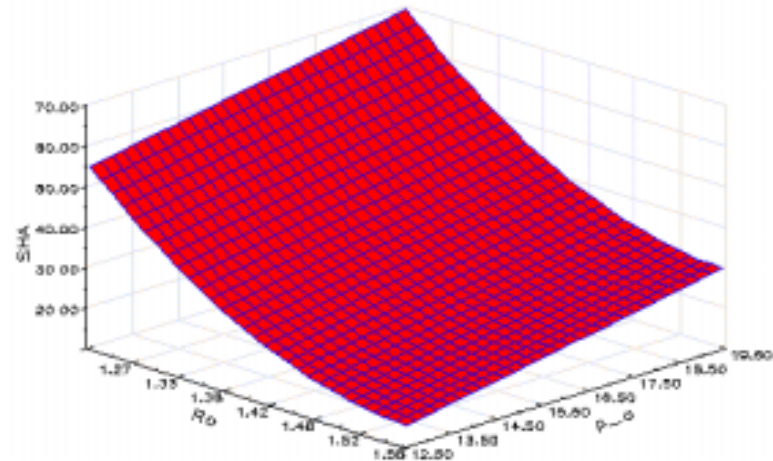
767-400 Raked Wingtip Front Spar DOE Sensitivity Analysis



Conventional Approach

- 32-Runs for Simple DOE
- 4-Months Calendar Time to Set-Up and Solve
- Computer (time) intense
- 216-Hrs Actual Labor to Complete
- Labor-Intense Data Reduction

RDCS Sensitivity Analysis Plus Design Scan

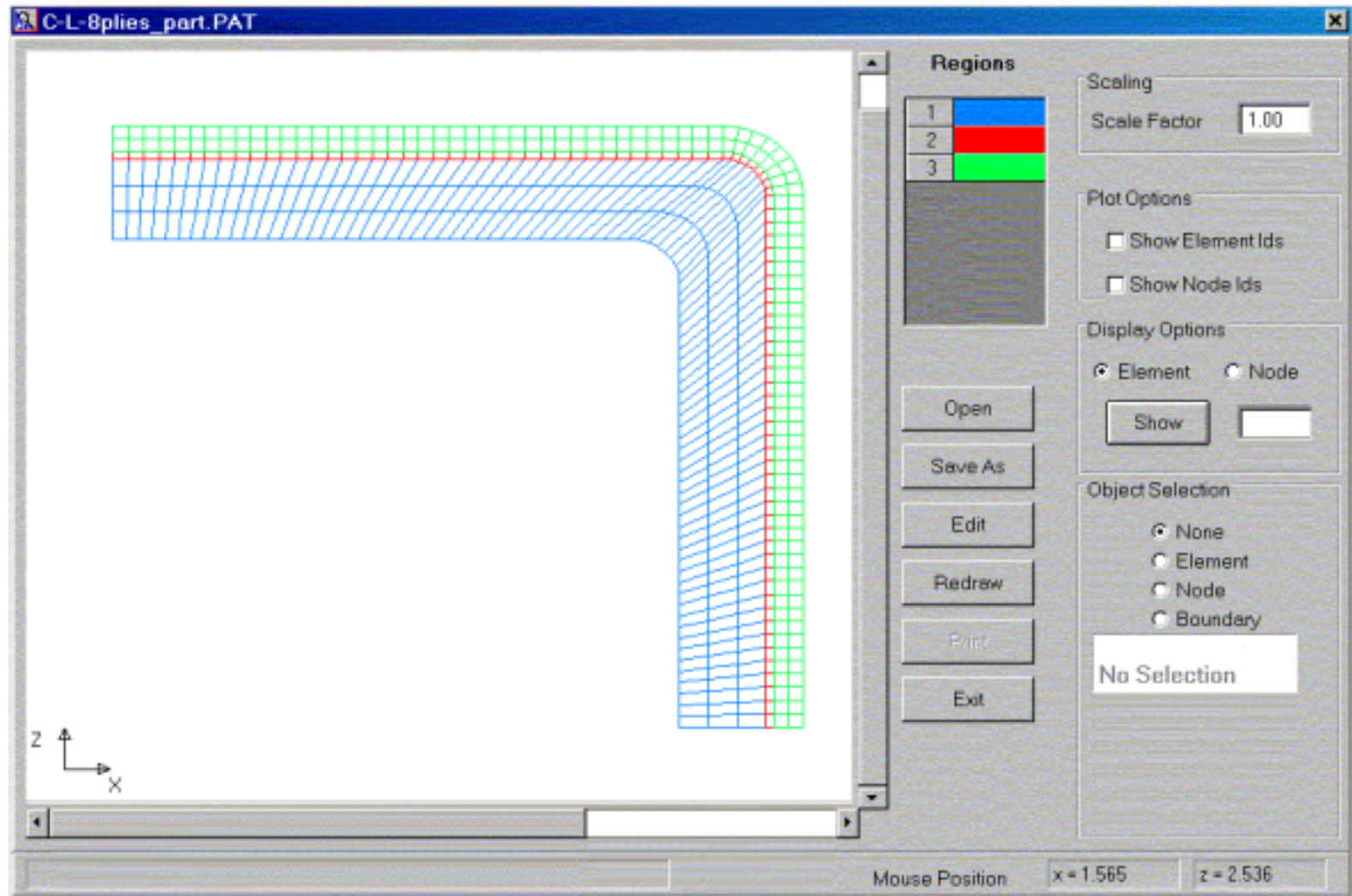


Integrated with RDCS

- 127-runs for Sensitivity Analysis and Design Scan
- 1-2 Weeks Calendar Time to Set-Up and Solve
- User Isolated from Intense Interaction with Multiple Codes
- 28-Hrs. Actual Labor to Complete
- Automated Data Reduction and Graphics



Initial Application of Processing Module: L-Bracket Example Problem





Input Parameters for L-Bracket Example Problem Involve Variability

Variable	Nominal	Lower	Upper	Std. Dev.
Target Temp	250	240	260	3.3
Hold Time	60	50	120	**
Alpha C2	0.67	0.5	0.8	0.05
8552 CTE 1	6.0E-07	5.4E-07	6.6E-07	0.2E-07
Fiber E11	2.73E+11			6.80E+09
Invar CTE	6.0E-07	5.4E-07	6.6E-07	0.2E-07
Theta_0	-45.0	-43.0	-47.0	0.667
Theta_7	-45.0	-43.0	-47.0	0.667

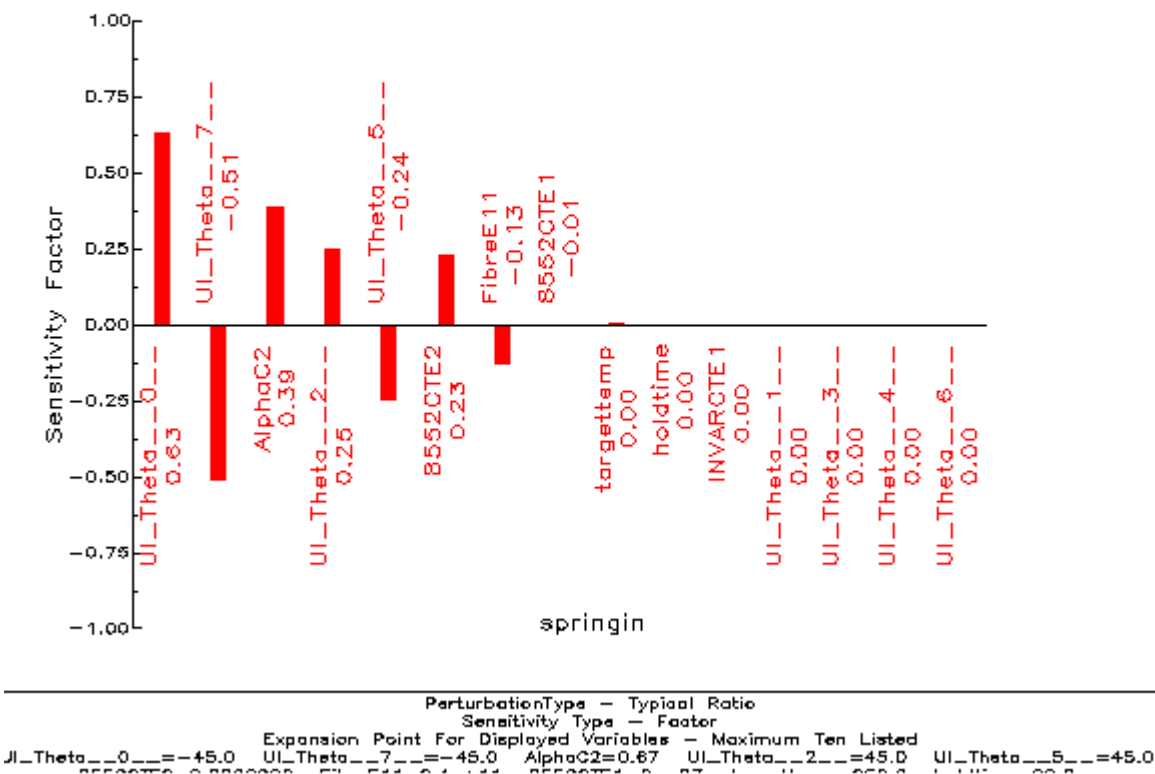
Hold Time was modeled using a 3-parameter Weibull Distribution
 $X_0 = 50$, Char. = 60.0 Alpha = 0.78



Identification of Parameters to Which Spring In is Sensitive

L-Bracket Example Problem

compro_46 – Sensitivity Analysis
Design Instance – sens





<h2>Summary of Responses</h2> <h3><i>L-Bracket Example Problem</i></h3>

Variable	Mean Response	Std. Dev. Response
Theta 7	1.057	0.106
Alpha C2	1.068	0.1175
Hold Time	1.06	0.1065
Target Temp	1.06	0.1055
All	1.012	0.115



Industry Benefits from AIM



- **Cost, schedule, performance with confidence factor**
- **Focus based on needs**
- **Knowledge management – orchestrated models, simulations, experiments to maximize useful information**
- **Built on building block methodology while facilitating discipline integration**
- **Internet access**
- **Path from criteria based to probabilistic based approaches**
- **Platform support for changes – bill of materials, pedigree, re-certification**
- **Design process application**
- **The best of emergent modeling and explicit modeling**
- **Applications to other problem sets**

Improve productivity, facilitate radically new approaches to material insertion





Accelerated Insertion of Materials -- Composites (AIM-C)



Wrap Up

- AIM attempting to provide methodology and tools to enable integrated product teams to accelerate insertion of materials into products
- Barrier -- Confidence in material “which is intimately tied to the reliability of knowledge of the state of material throughout production and use”
- AIM tool under development includes
 - A quantitative tool set
 - Combination of analysis and test
 - Requires management of uncertainty and error
 - Challenge to materials community -- Understand and manage uncertainty and error in models and tests
 - A qualitative tool set
 - Capture lessons learned, experience
 - Anchor AIM to established practices